

Measurement of the Higgs Cross Section and Mass with Linear Colliders

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We report on the accuracy of the measurement of the Higgs boson mass and the total cross section of the process $e^+e^- \rightarrow ZH$ that would be achieved in a linear collider operating at a centre-of-mass energy of 350 GeV, assuming an integrated luminosity of 500 fb^{-1} . For that we have exploited the recoil mass off the Z using its leptonic decays into electron and muon pairs. The Higgs mass is determined with 150 MeV accuracy, the recoil mass resolution is about 1.5 GeV and the cross section is obtained with a statistical error of 3%.

1 Introduction

An e^+e^- collider with centre-of-mass energy \sqrt{s} of a few hundred GeV is particularly well suited to discover the Higgs boson if its mass is of $\mathcal{O}(100 \text{ GeV})$. Even in the case a particle interpreted as the Higgs boson was discovered already at another accelerator like LHC a linear collider is the only facility which allows to identify it as the Higgs boson predicted by the Standard Model¹. Crucial tests here are the values the couplings to gauge bosons and fermions. A quantity which depends on the couplings to the gauge bosons is the Higgs boson production cross section in the Higgs-strahlung or fusion process. The couplings to different fermion species are accessible by the measurement of the Higgs boson branching fractions. For this the production cross section of Higgs bosons is needed.

In this letter, we present a method to measure the cross section for the production of the Higgs boson independent of its branching fractions exploiting the recoil-mass method. We take into account the detector resolutions, the efficiencies of lepton identification and the relevant background processes.

2 Experimental Conditions

The study is performed for a linear collider operated at a centre-of-mass energy of 350 GeV. The assumed data statistics corresponds to an integrated luminosity of 500 fb^{-1} . The detector used in the simulation follows the proposal

presented in the TESTA Conceptual Design Report².

The interaction region is surrounded by a central tracker consisting of a silicon microvertex detector as the innermost part and a time projection chamber. In the radial direction follows an electromagnetic calorimeter, a hadron calorimeter, the coils of a superconducting magnet and an instrumented iron flux return yoke. The solenoidal magnetic field is 3 Tesla. The central tracker momentum resolution is $\sigma_{p_t}/p_t = 7 \cdot 10^{-5} \cdot p_t$ (GeV) and the energy resolution of the electromagnetic calorimeter $\sigma_E/E = 10\%/\sqrt{E} + 0.6\%$, E in GeV. The polar angular coverage of the central tracker maintaining the resolution is $|\cos \theta| < 0.85$, above this range the tracking resolution degrades. The electromagnetic and hadron calorimeters cover the region $|\cos \theta| < 0.996$, maintaining the resolution over the whole angular range. The simulation of the detector is done with the program SIMDET³.

3 Method of the Measurement

In the energy range considered the dominant process for Higgs boson production in the Standard Model is $e^+e^- \rightarrow ZH$. To determine the cross section for this process, $\sigma(ZH)$, we exploit leptonic decays of the Z boson, $Z \rightarrow e^+e^-$ and $Z \rightarrow \mu^+\mu^-$. These final states exhibit a clean signature in the detector. Hence they are easily selected with selection efficiencies expected to be independent of the decay mode of the Higgs boson. Due to the excellent momentum and energy resolution the Z is well reconstructed and the recoil mass against the Z, $m_X^2 = s - 2 \cdot \sqrt{s} \cdot E_Z + m_Z^2$, is exploited to detect the Higgs boson and to measure its production cross section. Here E_Z and m_Z are the energy and the mass of the Z. Bremsstrahlung and beamstrahlung are taken into account.

3.1 Signal and Background

Events of the signal, $e^+e^- \rightarrow ZH$, are generated using the PYTHIA program⁴ for Higgs boson masses of 120, 140 and 160 GeV. The Standard Model cross sections and the expected event numbers corresponding to a luminosity of 500 fb^{-1} are given in Table 1.

The following background processes are considered: $e^+e^- \rightarrow e^+e^-f\bar{f}$, $e^+e^- \rightarrow f\bar{f}(\gamma)$, $e^+e^- \rightarrow W^+W^-$ and $e^+e^- \rightarrow ZZ$. The number of events expected in each of these processes is given in Table 2.

Initial state bremsstrahlung is simulated with PYTHIA. Beamstrahlung is taken into account using the CIRCE program⁵. The impact of beamstrahlung on the recoil mass is illustrated in Figure 1. Beamstrahlung broadens the recoil boson mass distribution and hence is of importance for this study.

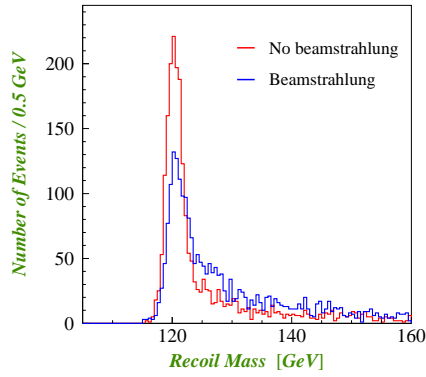


Figure 1: The recoil mass spectra off the Z with and without taking into account beamstrahlung.

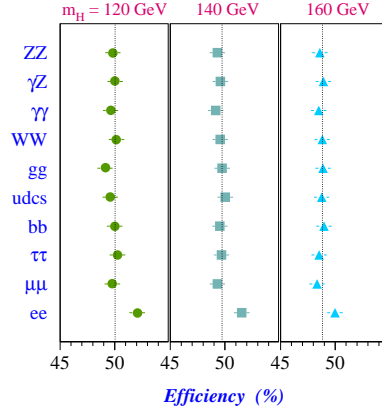


Figure 2: The selection efficiency of $e^+e^- \rightarrow ZH \rightarrow e^+e^-X$ for several Higgs boson decay modes.

Both signal and background events are processed by the detector simulation package SIMDET. The output in terms of reconstructed track momenta and calorimetric cluster energies is used for the forthcoming analysis.

3.2 Lepton Identification and Selection of $Z \rightarrow \ell^+\ell^-$

Electrons are identified as energy deposits in the electromagnetic calorimeter whose shape is compatible with the expectation for an electromagnetic shower and with a matched track in the central tracker. The measured track momentum and shower energy must be in agreement within 5% and the shower leakage into the hadron calorimeter must be less than 2 GeV. Muons are tracks pointing to energy deposits in the calorimeters which are consistent with the expectation for a minimum ionising particle. Both electrons and muons must have momenta larger than 10 GeV and fulfil the polar angle cut $|\cos\theta| < 0.9$.

m_H (GeV)	σ (fb)	events
120	5.3	$2.6 \cdot 10^3$
140	4.3	$2.1 \cdot 10^3$
160	3.6	$1.8 \cdot 10^3$

Table 1: The cross section for the process $e^+e^- \rightarrow ZH \rightarrow \ell^+\ell^-H$ for different Higgs boson masses and the number of expected events for a luminosity of 500 fb^{-1} .

background process	events
$e^+e^- \rightarrow e^+e^-ff$	$2.0 \cdot 10^9$
$e^+e^- \rightarrow f\bar{f}(\gamma)$	$2.0 \cdot 10^7$
$e^+e^- \rightarrow W^+W^-$	$7.0 \cdot 10^6$
$e^+e^- \rightarrow ZZ$	$5.0 \cdot 10^5$

Table 2: The number of events expected for several background sources.

The mass of the leptons is required to be within 5 GeV equal to the Z mass. To suppress background from $e^+e^- \rightarrow ZZ$, the production polar angle of the two-lepton system must be $|\cos\theta_{\ell\ell}| < 0.6$.

The selection efficiencies for the processes $e^+e^- \rightarrow ZH \rightarrow e^+e^-X$ and $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^-X$ are listed in Table 3. These efficiencies are independent on the Higgs boson decay mode. This is demonstrated in Figure 2 for the channel $e^+e^- \rightarrow ZH \rightarrow e^+e^-X$. The only exception is the case when the Higgs boson decays like the detected Z, $H \rightarrow e^+e^-$. This mode is negligible in the Standard Model. The results for the channel $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^-X$ are very similar.

m_H (GeV)	e^+e^- efficiency	$H\mu^+\mu^-$ efficiency
120	50.4 ± 1.0	52.8 ± 1.0
140	49.4 ± 1.0	51.7 ± 1.0
160	48.8 ± 1.0	51.3 ± 1.0

Table 3: The selection efficiencies for $e^+e^- \rightarrow ZH \rightarrow \ell^+\ell^-X$ processes for several Higgs boson masses.

3.3 Results

Figure 3 shows the recoil mass distribution obtained for a $m_H = 120$ GeV signal and the background contribution for the channel $e^+e^- \rightarrow ZH \rightarrow e^+e^-X$. The Higgs boson appears well on top of a small background, mainly from $e^+e^- \rightarrow ZZ$ events.

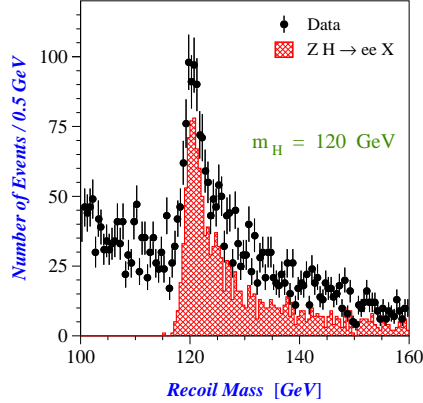


Figure 3: The recoil mass spectra off the Z in $e^+e^- \rightarrow ZH \rightarrow e^+e^-X$ events.

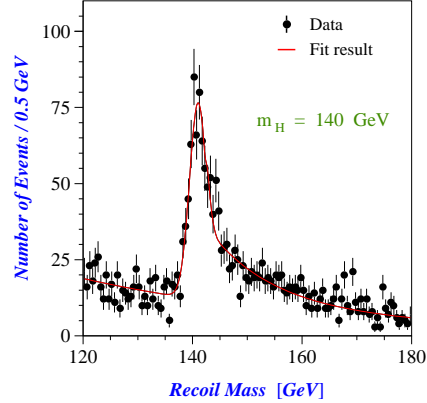


Figure 4: The fit of the recoil mass spectra off the Z in $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^-X$ events.

The recoil mass spectra are fitted with a superposition of a signal and a background distribution. To account for the asymmetric signal shape two approaches are used. One describes the left side of the signal as a Gaussian and the right side as the sum of a Gaussian and an exponential function. The other uses an Edgeworth expansion⁶ of a Gaussian. The background shape is parametrised as an exponential.

The fit is performed with the mass (m_X), the width (σ_X) and the normalisation of the signal as free parameters. A typical result is shown in Figure 4 for a sample generated with a Higgs boson mass $m_H = 140$ GeV.

The masses m_X agree well with the values used in the signal generation. The accuracy of the mass determination is about 150 MeV. The width of the distribution, reflecting the recoil mass resolution, is about 1.5 GeV. The cross sections are obtained with a statistical error of 3% for the two final states $e^+e^- \rightarrow ZH \rightarrow e^+e^-X$ and $e^+e^- \rightarrow ZH \rightarrow \mu^+\mu^-X$ combined. The obtained values for the production cross sections are given in Table 4. The systematic error includes the uncertainties from the selection efficiencies and a luminosity measurement error of one 1%.

m_H (GeV)	σ (fb) $Z \rightarrow e^+e^-$	σ (fb) $Z \rightarrow \mu^+\mu^-$
120	$5.26 \pm 0.18 \pm 0.13$	$5.35 \pm 0.21 \pm 0.13$
140	$4.38 \pm 0.18 \pm 0.11$	$4.39 \pm 0.17 \pm 0.10$
160	$3.68 \pm 0.17 \pm 0.09$	$3.52 \pm 0.15 \pm 0.08$

Table 4: The fit results for the Higgs boson production cross section.

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